

Performance of Hydrated Cement Treated Crushed Rock Base as a Road Base Material in Western Australia

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ABSTRACT

Hydrated Cement Treated Crushed Rock Base (HCTCRB) is produced by adding 2%-Portland cement with standard crushed rock base. The mixture is disturbed after the specific hydration period to prevent setting up and retain its unbound property. HCTCRB has been commonly adopted for Western Australian roads, however based on empirical method and experiences. Thus, the characterisation of HCTCRB following the pavement mechanistic approach is needed. This paper aims to presents the performances of HCTCRB in terms of permanent deformation and resilient modulus. The repeated load triaxial tests were performed to study the performances of HCTCRB that affected by manufacturing (hydration period) and construction procedures (amount of water added during compaction and dry back). This study has found that HCTCRB exhibited the stress dependent behaviour. All these studied factors significantly affect the resilient performances of HCTCRB in dissimilar trends. The certain impact on the material performances related to the hydration periods still could not be concluded. The higher water addition even at the optimum moisture content of HCTCRB resulted in the poorer performances, although it induced the higher dry density, which indicated that the HCTCRB is still susceptibility to moisture content. The dryback process has potential to improve the material performances of the material in different level which depends on amount of additional water. All the tested results indicated the significant influence of moisture content to the performances of HCTCRB with regardless of the dry density.

Keywords: base course material, cement-modified material, hydrated cement treated crushed rock base, crushed cock base, pavement

1 INTRODUCTION

The flexible pavements in Western Australia (WA) have a surface of approximately 30 mm. Thus, traffic loads on the road surface result in high stress levels on its proximity. High quality aggregates are therefore required for the base course layer. These requirements led to the improvement of base course material in WA. Crushed rock base (CRB) was the traditional base course material used in WA. CRB is an unbound granular material that has the insufficient capability to resist the increased load and growth of today's traffic. Moreover, CRB is moisture-sensitive which accelerates pavement deterioration.

The cement stabilisation technique has been employed in WA with additional procedures of hydration and retreated processes. Small amounts of cement are blended with standard CRB at optimum amount of water obtained by MRWA Test Method WA 133.1 (Main Roads Western Australia 2007). The mixture is stockpiled for minimum seven day-hydration period. Unlike the common cement treated base, as after the hydration period it is retreated to break bonds generated during the hydration time. This material became Hydrated Cement Treated Crushed Rock Base (HCTCRB) which is a unique base course material used in WA. HCTCRB is expected to provide higher strength and lower moisture sensitivity than CRB, while prevent the bound characteristics that lead to fatigue cracking problems as of cement treated base (Butkus 2004).

HCTCRB has been commonly adopted for Western Australian roads based on empirical method and experiences. Experience in HCTCRB use has been gained over time. It has been found that during manufacture and construction works, many factors lead to uncertainty when using the material, such as cement content, hydration period, water addition, compaction processes, curing methods and

dryback process. This uncertainty has contributed to the early damage of some new highways and roads. Some of highways and roads in WA are exhibiting extensive surface damage as a result of increasing traffic volume. However, explanations for the damage occurring under present conditions are difficult to determine and assess. Accordingly, an understanding of the material characteristics, in accordance with the pavement mechanistic approach, is strongly advised to maximise its use. Our study, which is a part of the project supported by the Australian Research Council (ARC) under the Linkage Scheme, is designed to further standardise HCTCRB's manufacture and construction, and overcome doubts regarding its use.

2 EXPERIMENTAL WORKS

2.1 Materials

The crushed rock samples were collected from a local Gosnells quarry to produce HCTCRB. The significant properties of CRB were taken in accordance with MRWA specifications (Main Roads Western Australia 2008). The cement used in this study was General Purpose Portland Cement (type GP), conforming to the standard AS 3972-1997 (Australian Standard 1997).

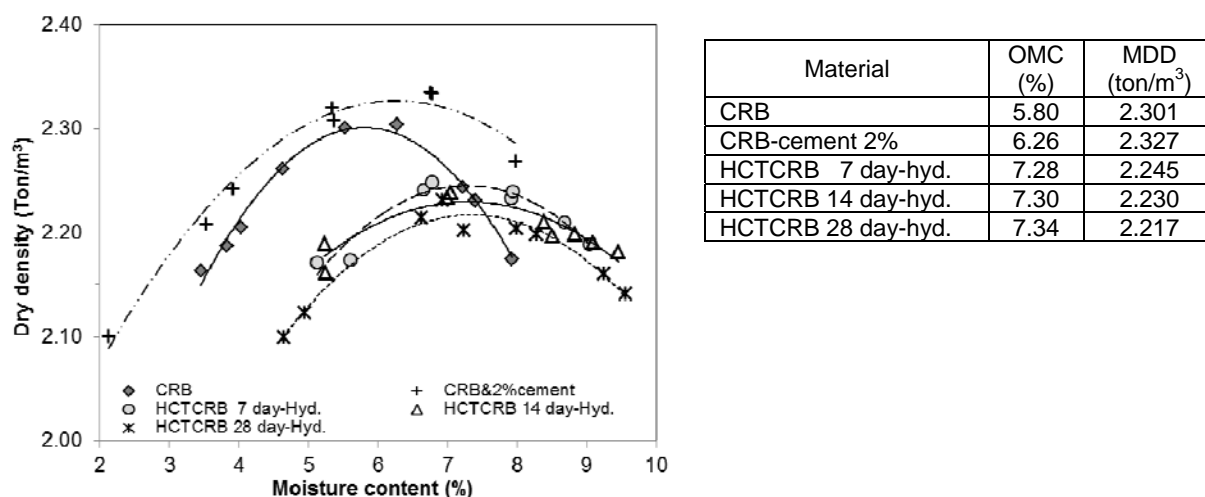


Figure 1. Moisture-density relationship of CRB, CRB-cement mix and HCTCRB (for 7, 14 and 28 days of hydration periods)

The moisture-dry density relationships of materials were determined using modified compaction method following the standard test WA 133.1 (Main Roads Western Australia 2007). In this study, HCTCRB samples were prepared, based on the CRB-cement compaction test result of 2 %-cement and 6.26%-water. CRB and cement were mixed and kept in sealed plastic bags for 7, 14 and 28 days of hydration periods. Each mix was retreated to finish manufacturing process of HCTCRB once the individual hydration time was due. The modified compaction tests were then performed for these three HCTCRB sorts. All compaction curves, the OMC and MDD of related materials are presented in Figure 1.

Compare to the CRB, the OMC of HCTCRB increased dramatically by 25.5% to 26.5%, while the corresponding MDD slightly decreased by 2.4% to 3.6%. Reduction of MDD in HCTCRB samples are caused by its poorer gradation compare to that of CRB. The gradation curves of HCTCRB shifted to the right of CRB curve and were below the lower limit of the specification (Chummuneerat et al. 2011). This occurrence caused by lack of fine content as a result of cementitious reaction with fine particles of CRB forming larger grains. The slight increases OMC but minor decreases in MDD for longer hydration periods were observed amongst these three types of HCTCRB.

2.2 Specimen preparation

After completion of retreated processes of the hydrated mixtures, all tested specimens were prepared according to modified compaction method in mould size of 200 mm-height and 100 mm-diameter. Material for each specimen was divided and compacted in evenly eight layers. Each layer was

subjected to 25 blows of 4.9 kg weight of hammer and 450 mm drop height which provided the 21.6 Joule per blow. The top of each layer was scarified about 6 mm-depth prior addition of material for next layer. All specimens were cured for 28 days at controlled temperature (25 degree Celsius) prior involved dryback process and set up to the testing machine.

2.3 Variation of the studied factors

This study investigated the effect of hydration periods, water addition during compaction and dryback on the permanent deformation and resilient modulus of HCTCRB. Effect of hydration periods were studied at 7, 14 and 28 days. There were three different levels of the water addition, type A, B and C which stand for no additional water, added water to OMC of CRB-cement mixture (6.26%) and added water to OMC of individual hydration period (see Figure 1). After 28 days of curing, the specimens had been dried during dryback process prior to the tests. Three degrees of dryback were used i.e. no dryback, dryback the sample to 80% of OMC and dryback the sample to 60% of OMC.

2.4 Repeated load triaxial (RLT) tests

The mechanical properties of materials such as resilient modulus (M_R) and permanent deformation (PD) were investigated by repeated load triaxial (RLT) tests, followed the Austroads standard test method AG: PT/T053 (Austroads 2007). The repeated vertical force waveform has a period of 3 s with rise and fall times of up to 0.3 s, and a load pulse width of 1 s. Permanent deformation tests were performed using three dynamic deviator stressors (σ_d), 350, 450 and 550 kPa at constant confining pressures (σ_3) of 50 kPa. At each stress stage, the machine applied ten thousand repetitions of a vertical force. The resilient modulus tests involve 66 stress stages of different deviator and confining stresses to simulate the sophisticated traffic loadings. The stress ratio between deviator stress and confining stress (σ_d / σ_3) varied from 2 at the first stage to 25 at the final stage. Each specimen was subjected to minimum one thousand cycles of preconditioning and minimum fifty cycle-loadings at each stress stage.

3 TEST RESULTS

The effects of manufacturing (hydration period) and construction procedures (water addition during compaction and dryback) on performances of the base course materials used in WA were evaluated. The testing results indicated the stress dependency of the tested materials. All impacts of these studied factors contributed to the material performances are described in the succeeding parts.

3.1 Effect of hydration period and water addition during compaction

This section reports the investigation of the PD and M_R of HCTCRB samples of 7, 14 and 28 day- of hydration periods with 3 type of water addition, type A, B and C. All specimens were tested immediately after 28 days of curing time without dryback process. All specimens were compact at identical energy but different moisture content which resulted in disparate dry density. Generally, the dry density of type A and B samples were lower than that of type C as a result of type A and B samples were compacted at the dried side of the individual OMC. The dry density of all tested specimen with respect to the individual MDD (see Figure 1) are summarised in Table 1.

Table 1: Dry density of the tested specimens with respect to the individual MDD

Hydration period	Type A	Type B	Type C
7 days	93.7% MDD	95.8% MDD	98.4% MDD
14 days	94.1% MDD	99.6% MDD	98.3% MDD
28 days	94.1% MDD	97.4% MDD	98.6% MDD

Figure 2 illustrates the RLT test results of all specimens described above. All specimens are symbolised, e.g. 7A represents the sample of 7 day-hydration period and type A (no water addition during compaction).

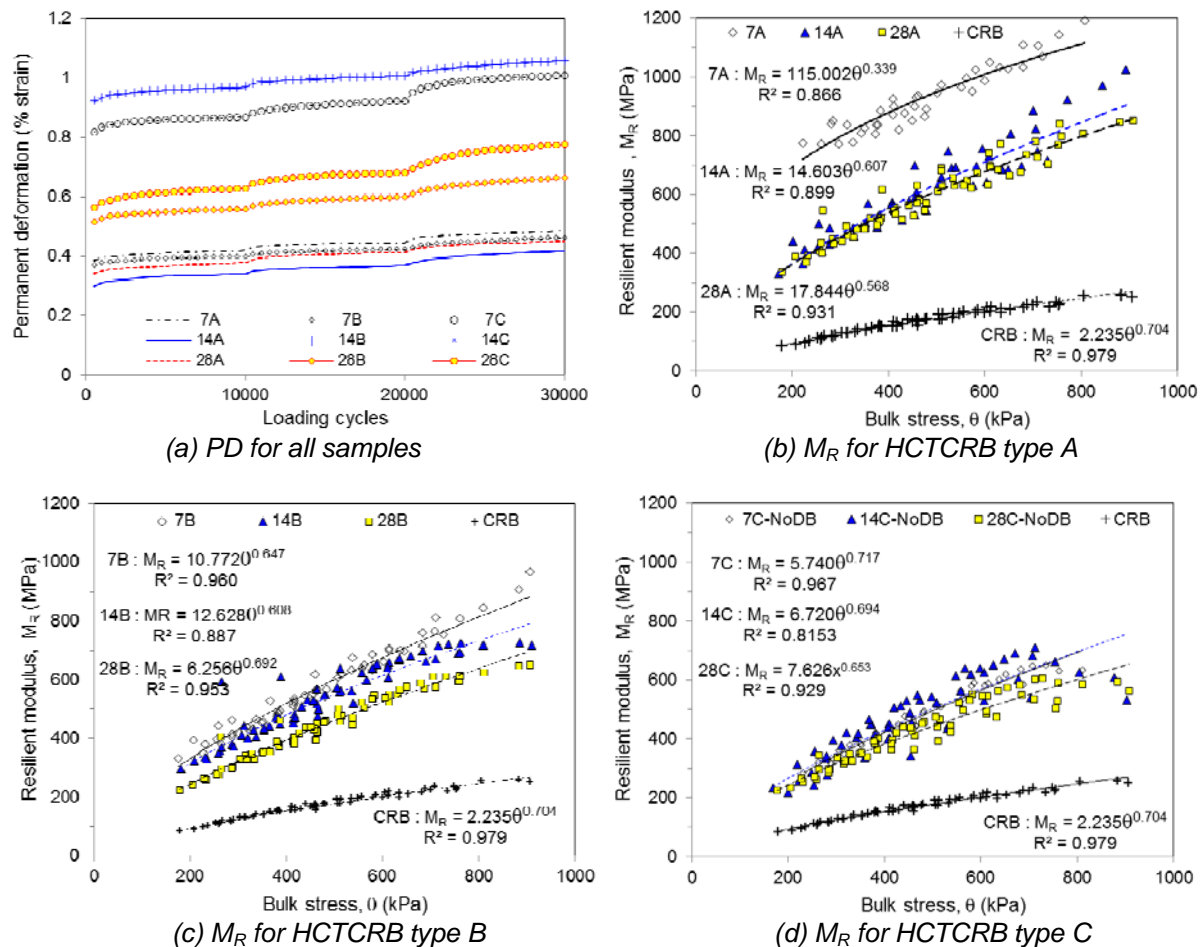


Figure 2. Repeated load triaxial test results of HCTCRB with variation of hydration period and water addition (no dryback)

The results of type A samples indicated that specimen 14A showed the best performance in terms of PD among three sorts of hydration period while 7A was the weakest sample. The % strain of 7A, 14A and 28A were 0.48, 0.42 and 0.45 respectively. Contrary, 7A sample provided the highest M_R values which ranged from 700-1200 MPa, followed by 14 and 28 day-hydration period which varied between 300-1000 and 300-850 respectively.

In case of type B, sample of 7B showed the best PD performance while 14B was the weakest sample even though it was the densest sample. The % strain were 0.46 for 7B, 1.06 for 14B and 0.66 for 28B. The 7B sample also provided the highest M_R values which range from 300-1000 MPa. The M_R for 14B and 28B were 300-740 and 200-650 MPa respectively. Lastly, for type C samples, 28C showed the best performance in terms of PD while 14C was the weakest sample. The % strain of 1.01, 1.69 (beyond the plotted area) and 0.78 were observed for 7C, 14C and 28C respectively. However, 14C provided the highest M_R values which ranging from 200-700 MPa. Sample 7C also provided minor different results to that of the 14C which varied from 200-650 MPa, The M_R of 28C sample ranged from 200-600 which was the worst sample.

The samples of 7 day-hydration period showed the highest M_R values amongst these three types of water addition, followed by the sample of 14 and 28 days of hydration periods. Nevertheless, the related trends of PD to the hydration periods still could not be found. Addition of water to the OMC of HCTCRB i.e. type C, provided the worst PD and M_R performances although the samples achieved more than 98% of MDD. The effect of hydration period on HCTCRB performances could not be concluded. The moisture content of the tested samples played the important roles on the RLT results with regardless of the dry density. The higher water addition up to the optimum moisture content of HCTCRB resulted in the poorer performances even it induced the higher dry density which indicated that the HCTCRB is still susceptibility to moisture content.

3.2 Effect of dryback process

The samples of 28 days of hydration period with three types of water addition (A, B and C) were tested to examine the effect of dryback process at three different level i.e. no dryback, dryback to 80% of OMC and dryback to 60% of OMC. The moisture content of the HCTCRB at 28 days of hydration period dropped to 80% of OMC as a consequence of water consumption through hydration reaction and curing process. Therefore, sample 28A that was dried to 80% OMC and sample 28A that was not subjected to dryback was the same specimen. The average moisture content after curing were 97.9% OMC for type B and 97.2% OMC for type C samples. The average dry density with respect to MDD of sample type A, B and C were 93.4%, 97.6% and 98.7% respectively. The series of PD and MR results are presented in Figure 3. Symbol in Figure 3 such as 28B-80DB represents the specimen of 28 day-hydration period which was prepared by water addition type B and dried to 80% of its OMC.

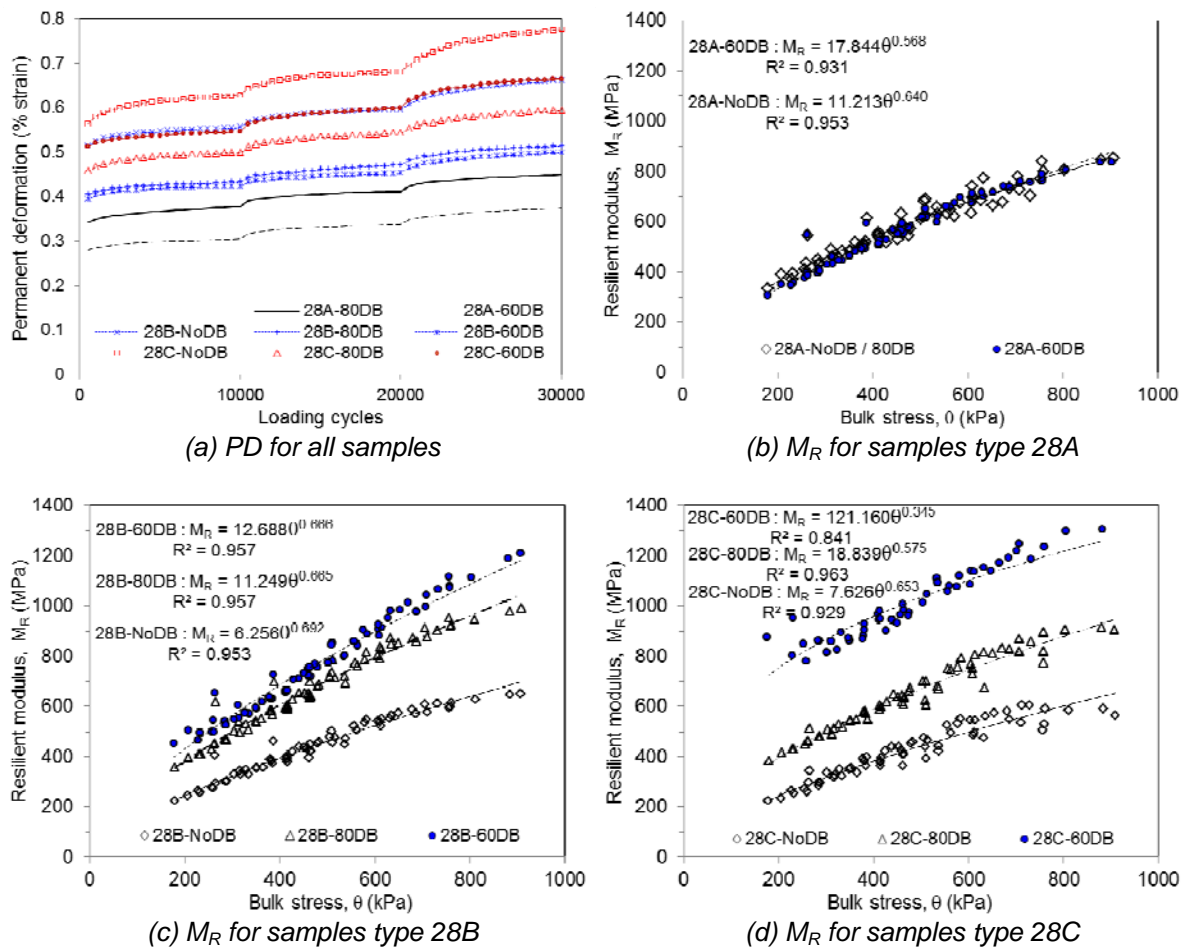


Figure 3. Repeated load triaxial test results of HCTCRB, 28 days of hydration period, with variation of water addition and degree of dryback

PD of samples type 28A reduced from 0.45 to 0.38 %strain as the moisture content decreased from 80% to 60% of its OMC. For type 28B, the results showed the small different between PD of samples dried to 80% and 60% OMC. The % strain were 0.66, 0.51 and 0.50 for the samples of no dryback, 80%OMC and 60%OMC respectively. PD of specimen type C decreased from 0.78 to 0.60 of % strain while its moisture content dropped from 97.2% to 80% of OMC. However, the driest sample (60% OMC) deformed inauspiciously to 0.66 % strain which was greater than that of the 80% OMC. Two samples of 28A provided the similar M_R , varied from 300 to 900 Mpa. For sample 28B, M_R increased from the range of 200-700 Mpa to 350-1000 MPa and 400-1200 Mpa as a result of moisture declined from 97.6% to 80% and 60% of OMC. The M_R values of sample 28C were 200-650 for no dryback sample, 380-900 for the sample dryback to 80%OMC and 800-1300 MPa for sample dryback to 60%OMC.

Higher additional water during compaction can lead to the inferior PD and M_R performance (compared to the sample without additional water during compaction). Although the samples of type B and C were dried to the level with sample type A, its permanent strains were still more defective than type A. These incidences reflect the impact of water addition during compaction to the PD resistance. Contrary, M_R of sample type 28B and 28C could be improved during dryback process and superior to that of type 28A at the same moisture content. The results stated that dryback process which reduced the moisture content of the specimen improved the material responses. The drier sample, the better will be PD and M_R performances. Apart from that, type 28A samples provided the best PD performances and comparable M_R values even though its dry density was lower than the other two. All these results indicate the significant influence of moisture content to the performances of HCTCRB.

4 CONCLUSION

This study examined the resilient modulus (M_R) and permanent deformation (PD) of HCTCRB conducted under various conditions such as hydration periods, water addition during compaction and dryback. The hydration periods of 7, 14 and 28 days were evaluated. There were three different levels of the water addition, type A, B and C which stand for no additional water, added water to OMC of CRB-cement mixture (6.26%) and added water to OMC of individual hydration period. Finally, the specimens involved dryback process prior to the tests. Three degrees of dryback were examined i.e. no dryback, dryback to 80% of OMC and dryback to 60% of OMC. The major conclusions obtained from the material characterisation are as follows.

This study has found that HCTCRB exhibited the stress dependent behaviour. The results also indicated that the hydration periods, water addition during compaction and dryback significantly affect the performances of HCTCRB in different manners. These findings suggest that in general the samples of 7 day-hydration period showed the highest M_R values amongst these three types of water addition, followed by the sample of 14 and 28 days of hydration periods. However, the certain related trends of PD to the hydration periods still could not be concluded.

Higher addition of water during compaction leads to the inferior PD and M_R performance (compared to the sample without additional water) even though the samples achieved the higher dry density. Although the samples of type B and C were dried to the same level with sample type A, PD values could be reduced but still higher than type A. Contrary, its M_R could be improved and superior to that of type A at the same moisture content. The dryback process has potential to improve the material performances of the material in different level which depends on amount of additional water. Apart from that, type 28A samples provided the best PD performances and comparable M_R values even its dry density was lower than the other two (28B and 28C). The higher water addition up to the OMC of HCTCRB resulted in the poorer performances even it induced the higher dry density which indicated that the HCTCRB is still susceptible to moisture content. All these results indicated the significant influence of moisture content to the performances of HCTCRB with regardless of the dry density.

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